The Higgs Boson

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Presentation Outline

- The Standard Model
- The Higgs Mechanism
  - Higgs Field/Higgs Boson
  - Analogies
- Finding the Higgs Boson
  - LEP – Unconfirmed detection
  - LHC – Expected to find Higgs or set lower limit
  - How to make a Higgs
- Summary
Taking Things Apart

- Everyday objects made up of molecules
- Molecules made up of atoms
- Atoms made up of protons and neutrons
- Nucleons made up of quarks
- Why do quarks have different masses?
- The Higgs Boson!
The Standard Model

- Elementary Particles
  - Fermions
    - Quarks: 6 flavors
    - Leptons: 3 generations
  - Bosons - Force Carriers
    - Photon: EM
    - Gluon: Strong
    - $W^\pm$, $Z^0$: Weak
    - Graviton?: Gravitational
The Standard Model

- Elementary Particles
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The Standard Model From Scratch

- Start with the bosons (force carriers)
- Assume fundamental laws and symmetries of nature
  - i.e. charge conservation and certain gauge symmetries: $SU(3) \times SU(2) \times U(1)$
- All the interactions between the particles of the Standard Model are specified by the Lagrangian
- No mass term for gauge particles can occur in the Lagrangian to preserve symmetries
- Conclusion: All gauge particles must be massless
Experimental and Theoretical Problems

- Why can’t we let the bosons be massless?
  - Range of force inversely proportional to mass of exchanged particles
  - Range of weak interaction very short (~$10^{-18}$ m), which corresponds to mass for exchanged particle

- Why can’t we just add in a mass term?
  - Addition of mass term is not gauge invariant
  - Gauge invariance crucial to avoid infinities in theory

- A solution to both problems: Spontaneous symmetry breaking
Spontaneous Symmetry Breaking in Ferromagnetism
Enter the Higgs Mechanism

- Introduce complex scalar field
- Ambiguous vacuum expectation value (vev)
- Higgs hides symmetry of weak and EM interactions
- Predicted existence of Z bosons
- Electroweak theory is renormalizable
A Theory With Potential

- Potential
  \[ V(x,y,z) = (|H(x,y,z)|^2 - \nu^2)^2 \]
- Minimum and maximum:
  \[ |H(x,y,z)|^2 = \nu^2 \text{ and } H = 0 \]
- Symmetry broken with \( H = \nu e^{i\phi} \)
- Use gauge transformation to make \( H \) a real field
- Expand about minimum state
  \[ H(x^\mu) = (\nu + h(x^\mu))/2^{1/2} \]
- \( h(x^\mu) \) is the Higgs Field
Broken Symmetry

- Pencil with rotational symmetry
- Falls in some direction, breaking the symmetry
- Pencil represents the Higgs field
- Pencils coupled together; they all fall in same direction
- Their presence in vacuum influences waves traveling through it
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Physics of Solids Analogy

- Solid contains lattice of positively charged crystal atoms
- Conduction electrons attracted to lattice atoms
- Electrons moving through lattice cause it to move as if they had large effective mass
The Higgs Mechanism
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Mass of the Higgs Boson

- Dependent on mass of W boson and top quark
- New precision measure of top quark mass:
  - Top mass: $178 \pm 4 \text{ GeV/c}^2$
- Mass of Higgs Boson:
  - Lower limit: 114.4 GeV/c$^2$
  - Upper limit: 251 GeV/c$^2$
  - Most Probable: 117 GeV/c$^2$
Possible Higgs Events at LEP

- ALEPH, DELPHI, L3, OPAL
- ALEPH found four Higgs candidates in fall 2000
- Data cannot be confirmed or ruled out
- $e^+e^- \rightarrow bbbb$
- Provided lower limit on Higgs Boson
Possible Higgs Events at LEP

- Distribution minimum at 114.9 GeV/c²
- Probability of being background fluctuation 0.4%
- Small number of events
- Currently have ~2.7σ effect
- Waiting for 5σ to claim discovery
Large Hadron Collider (LHC)

- Located at CERN
  - On border of France and Switzerland
- About 27 km or 16.5 miles in circumference
- Used for collisions involving:
  - Protons
  - Heavy ions (such as lead, achieving collision energy 1150 TeV)
- Expected to begin operation in 2007
Four Ways to Make a Higgs
Important Things to Remember

- Particles believed to acquire mass through their coupling with the Higgs field
- If it exists, the Higgs plays a role in unifying the weak and EM interactions
- The existence of the Higgs boson has never been confirmed, but the LHC is expected to find it if it is in-line with current theories
- Many theories require there to be a Higgs
For More Information

- **The God Particle**, Leon Lederman
- **The Fundamental Particles and Their Interactions**, William Rolnick
- [http://hepwww.ph.qmw.ac.uk/epp/higgs.html](http://hepwww.ph.qmw.ac.uk/epp/higgs.html)